Role of Environmental Science in Tackling Plastic Pollution

Friederike Stock, Georg Reifferscheid, Nicole Brennholt, and Evgeniia Kostianaia

Contents

Abstract The book volume "Plastics in the Aquatic Environment – Part I: Current Status and Challenges" gives an overview about the role of environmental science and provides a sense of the global perspective in dealing with plastic pollution. The volume contains 15 chapters, with two additional chapters written by the editors containing introductory remarks and concluding notes on the role of environmental science in tackling the plastic pollution problem. These 15 chapters present and discuss challenges in research, related, for example, to microplastics analysis, impacts of plastic litter on aquatic environments, plastic waste management, bioplastics; they also review case studies of plastic pollution and contamination in the Philippines, Brazil, Albania, Slovenia, Russia and East Asia, as well as the Mediterranean Sea at large. This chapter provides an overview of the conclusions drawn by the authors of the chapters of this book volume and gives an overall final discussion of the challenges discussed herein.

Keywords Challenges, Open research questions, Plastic, Pollution

F. Stock (✉), G. Reifferscheid, and N. Brennholt
Department of Biochemistry, Ecotoxicology, German Federal Institute of Hydrology, Koblenz, Germany
e-mail: stock@bafg.de; reifferscheid@bafg.de; brennholt@bafg.de

E. Kostianaia
P.P. Shirshov Institute of Oceanology, Moscow, Russia
e-mail: evgeniia.kostianaia@ocean.ru

Friederike Stock, Georg Reifferscheid, Nicole Brennholt, and Evgeniia Kostianaia (eds.), *Plastics in the Aquatic Environment - Part I: Current Status and Challenges*, Hdb Env Chem (2022) 111: 487–496, DOI 10.1007/698_2021_793,

1 Introduction

The current book volume – "Plastics in the Aquatic Environment – Part I: Current Status and Challenges" – represents the first volume in the book project "Plastics in the Aquatic Environment", which also has a second volume "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution". The current book volume focuses on the chemical and biological aspects of plastic pollution, as well as on specific examples of impacts of plastic pollution and associated research in several countries and regions around the world, specifically Philippines, Brazil, Albania, Slovenia, Russia and East Asia, as well as the Mediterranean Sea at large. The second book volume, "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution", considers such aspects of the fight against plastic pollution as environmental policy, law and finance, nature conservation, education and human behaviour.

The authors represent a wide range of research institutions and organizations, such as the German Federal Institute of Hydrology (Koblenz, Germany), Institute of Plastics and Circular Economy (Leibniz University Hannover, Germany), Anglia Ruskin University (Cambridge, UK), Hellenic Centre for Marine Research (Institute of Marine Biological Resources and Inland Waters, Greece), Italian National Institute for Environmental Protection and Research (Bologna, Italy), National Institute of Oceanography and Applied Geophysics (Trieste, Italy), P.P. Shirshov Institute of Oceanology (Moscow, Russia), National University of Science and Technology MISIS (Moscow, Russia), Department of Engineering Science, University of Oxford (UK), Lomonosov Moscow State University (Russia), Skoltech Institute of Science and Technology (Moscow, Russia), Institute of Marine Biology (Odessa, Ukraine), UNESCO, BKV GmbH (Germany), University of Alicante (Spain), University of Ljubljana (Slovenia), Agricultural University of Tirana (Albania), Aleksandër Moisiu University of Durrës (Albania), National Sun Yat-sen University (Taiwan), Toyama Prefectural University (Japan), IndigoWaters Institute (Taiwan), Medipeace (Republic of Korea), University of the Philippines (Quezon city, Philippines), Marine and Environmental Sciences Centre (ISPA – Instituto Universitário, Lisbon, Portugal), Federal University of Paraná (Brazil), Federal University of Pernambuco (Brazil) and Russian State Hydrometeorological University (St. Petersburg, Russia).

Such a diverse spectrum of expertise has allowed, as we as editors hope, for an interesting and engaging discussion of some of the principal aspects of plastic research, such as microplastics analysis, impacts of plastic litter on aquatic environments, plastic waste management, bioplastics, as well as presentation of some specific research in certain countries. Seven chapters discuss plastic pollution research and approaches in such aquatic environments as the Mediterranean Sea at large, with some specific examples of Durrës Bay, Rodoni Bay, the Gulf of Drin and Shëngjini Bay in Albania and research in Slovenia, water bodies of Metro Manila in the Philippines, Brazilian freshwater and estuarine environments, the Russian part of the Baltic Sea, namely the Gulf of Finland and the South-East Baltic, and the aquatic environments of China, Japan, South Korea and Taiwan.

2 Overview of This Volume

The chapter by Stock et al. [1] presents a detailed overview about pitfalls, limitations, advantages and disadvantages in microplastic analyses (sampling, sample preparation and analysis). The authors underline that harmonization and standardization of sampling and analytical methods are still missing and that comparability of data is not yet given. Microplastics are heterogeneously distributed and replicates and repeated measurements are absolutely needed. A harmonized protocol should be implemented so that a better comparability of data is given and data can be used by other researchers. Moreover, critical parameters and limitations should always be reported. The generated data should also be validated and be usable for modelling studies as case studies only cover a small geographical area. In general, the authors point out that microplastics in environmental samples are very challenging as parameters, such as different sizes, shapes, colours, ages of polymers or biofilms, may influence the result of the analysis and the detection of microplastics. Therefore, the authors do not recommend the use of a specific method but to consider the main research question and to use a combination of analytical approaches.

Dierkes et al. [2] summarize analytical methods for analyzing microplastics in environmental samples. Although a diversity of methods exists, harmonization is not yet present. In order to implement measures for reducing microplastic emissions, Dierkes et al. emphasize the need for a reliable, fast and cheap identification method. The authors describe the advantages and differences between the methods. They do not suggest to use a specific method as they generate different information (number and size vs. mass). The size of the analyzed plastics should be considered as for example smaller particles (esp. <10 μm) present a large effort. Another important fact which should be taken into account is sample pretreatment which can be quite time-consuming (density separation, enzymatic or chemical digestion). The authors also point out the need to establish standardized protocols and harmonized quality standards.

In order to maintain the positive features of plastics while overcoming the negative ones, great hope is placed on the development of bioplastics. However, as Endres describes in his chapter "Biodegradable Plastics – End of Life Scenarios" [3], it is important to make a distinction between the biopolymer in its form as a macromolecule and the ready-to-use material. Furthermore, bio-based and biodegradable plastics should be differentiated. Bio-based plastics concern the raw material origin of the polymer feedstock, whereas biodegradability refers to an end of life option. Both features are independent of each other. Although biodegradability defines a material property which depends on the microstructure as well as the chemical structure of the material, in reality, biodegradability is a system feature, because there are many environmental conditions, ranging from industrial compost and sewage treatment plants to soils in a wide range of climatic regions, the beach, seabed and even the human body. Thus it is essential to offer exact data on environmental conditions, as well as points in time when a product or material is considered biodegradable. As regards compostability, test standards in some areas, such as bioplastics and other organic substances, cover well various environmental conditions. On the contrary, test standards in some other areas, for example, degradability in marine systems or soil, are few and are not able to present well complex environmental conditions. Aside from the formation of appropriate standards, future material development requires an advanced knowledge of the relationships between environmental conditions of habitats, microbiology and material parameters, on the one hand, and, on the other hand, ensuing degradation mechanisms and kinetics.

Green [4] points out that only few studies used environmental relevant concentrations of (micro)plastics so that biological and ecological consequences are difficult to decipher. The few studies using prevailing concentrations in the environment revealed mixed results. Therefore, it is necessary to conduct more research by simulating realistic concentrations of (micro)plastics, using mesocosm studies in the natural environment and to conduct experiments on a longer term so that effects can be better understood. Nevertheless, the present studies and their results can be transferred to future impacts as a 50-fold increase of microplastics is well probable in the environment from 2010 to 2100. The authors also show that some effects are already present at current environmental levels. When conducting experiments it is also very important to take into account parameters such as size, shape, chemical composition, abundance of the plastic debris, the type of organism or habitat being polluted, and the existence of other environmental stressors that may potentially affect any impacts [4]. In addition, it should also be noted that biodegradable plastics in natural environments may not decompose very fast and that they may have the same effects as non-biodegradable plastics. Thus, waste management of biodegradable plastics is also of high importance so that these plastics do not enter the environment.

The impact of plastic pollution on marine life (as demonstrated by the Mediterranean Sea) is a widespread phenomenon. Anastasopoulou and Fortibuoni [5] point out that the more research is conducted, the more impacted marine species are described. Different direct and indirect effects such as ingestion (predominantly studied), entanglement or substrates acting as a dispersal for organisms or pathogens prevail. Macroplastics have also been ingested by different species such as fish, birds, turtles and cetaceans. Not much is known about how additives and other contaminants of microplastics affect organisms. With regard to ingestion, the risk is perceived as lower for microplastics than for large plastic parts, as this has not been yet shown by researchers. In contrast, plastic waste leads to ingestion and entanglement and can provoke death and suffering of marine life, e.g. for seabirds, turtles and cetaceans. The published studies always refer to individuals and not to populations as these studies are hampered by different stressors (e.g. environmental and human-induced). Therefore, the role of microplastics may be veiled [5].

Sapozhnikov et al. [6] discuss in detail interactions of plastics with microorganisms and present published work as well as the results of their research of the last years. The main outcome of micro-fouling of different polymers in aquatic environments is that colonization by certain microorganisms occurs (especially diatoms). Microphytes from benthic communities, for instance, may settle on plastics and decompose it. Thereby, different benthic or periphytic species can be present at the same time on different polymers in one habitat. Thus, the presence of colonial microphyte settlements determines the mechanisms of plastic destruction. Research has also shown that certain species of bacteria use plastics as a carbon source. However, this work was done under laboratory conditions. Thus, more research is necessary to study these bacteria under natural conditions. Furthermore, there is some evidence that plastic has toxic effects on the growth and functioning of microorganisms themselves. Moreover, the authors state that it is well probable that a link exists between toxin production of potentially toxic microphytes and their presence on polymers. In addition, microorganisms use polymers as a transport path and thus spread around the world. It is possible that this transport leads to biological invasions. The authors also state that there are still knowledge gaps concerning biodegradation and the interaction with microorganisms.

Zandaryaa [7] from the UNESCO Division of Water Sciences gives an overview of microplastics in freshwater, its sources and pathways and their occurrence. The author summarizes the published studies about microplastics in freshwater environments of the last years and describes the relevance of microplastics with regard to an improved water quality and the UN 2030 Agenda Sustainable Development Goals. Microplastics are found all over the world in different environments. Despite the multitude of publications about microplastics in general, freshwater environments have only been studied for several years. Therefore, knowledge gaps occur. Data for monitoring microplastics in different environments are missing. Ecotoxicologial research has to be intensified in order to estimate risks, accumulation and exposure on organisms and risks of microplastics exposure to humans in drinking water are not known. The author also mentions the need to share knowledge and build research capacities with developing countries. Moreover, harmonization of methods and definitions are needed for better comparing data. Solutions for decreasing the pollution include microplastic reduction at the source along with sustainable consumption and production, replacing and banning plastic products, improving waste management and reducing and recycling plastic waste. This should not only be done with technological advances but also with policy approaches.

Cieplik presents the model “From Land to Sea – Model for the documentation of land-sourced plastic litter” and shows pathways and discharge sources into the North Sea, Baltic Sea and Black Sea [8]. The model aims at estimating origin, quantity and nature of improperly disposed plastic litter (micro- and macroplastics) originating from Germany. In the first step, identification of main discharge pathways and discharge sources took place. Then, a database was set up based on an established data model. In the second step, primary and secondary data were the basis for the calculation of discharge volumes. The results reveal that most plastics transported into the sea are macroplastics. However, the amounts of macroplastic litter differ. The Baltic Sea has the highest discharge as the river basins are characterized by a long coastline. The model also showed that about 80% discharge enters the North Sea, Baltic Sea and Black Sea via the pathways “rivers” and “coastal regions”. For the future, it is possible to include other regions and countries as well as other discharge pathways into the model.

In their chapter Horodytska et al. [9] have a critical look at plastic waste management and describe the current status and its weaknesses. Hereby, they differentiate between developed and developing countries. They show that sustainable waste management along with different collection, sorting and waste treatment systems are more predominant in developed countries. However, it is not clear in which system environmental benefits prevail. Possible recyclable materials may be collected separately. In general, mechanical recycling, chemical recycling, energy recovery and landfilling are waste treatment methods. Some European countries already prohibited landfilling as it is considered as the worst method. In developing countries, municipal collection strategies are lacking or are not efficient and therefore contribute to waste accumulation and environmental pollution. However, in developing countries an informal recycling sector has been established. Valuable and recyclable materials from waste on the streets, houses and landfills are picked up and sold by waste pickers, whose work conditions are horrendous. A circular economy, however, has not even been reached in developed countries although waste management is present and rising recycling rates occur. The study reveals that contamination and degradation reduce the value of possible recyclable material so that these products are downcycled. Therefore, it would be important to significantly improve the quality of recyclates.

The case study about Slovenia by Kalčikova and Gotvajn shows that the country has successfully implemented an environmentally sustainable waste management structure [10]. This has been done by awareness rising, social aspects, fines, education and work of NGOs as well as lowering the amount of waste and at the same time increasing the recycling rate. Despite the many efforts conducted, microplastic pollution is still present along the coasts. Therefore, the authors suggest improving the solid waste management and the wastewater treatment as this seems to be the main source of plastic pollution into the environment.

In their report on marine litter assessment on some beaches along the South-Eastern Adriatic coastline of Albania [11], Kolitari and Gjyli give detailed information about the amount and composition of litter. They found on average 0.219 items/m^2 (219 items/100 m; 152.3–313.3 items/100 m) beach litter. The report shows that shoreline sources (e.g. tourism and recreational activities), in addition to the poor waste management practices, are the main sources of beach litter deposited on surveyed beaches. Therefore, the authors recommend the following options based on the results of their research: actions to tackle cartons/Tetra Pak items, measures to deal with plastics, including single-use plastic items, more investments to set up landfills, and rehabilitation of the polluted Ishmi River by the means of water purification and dredging soil. Moreover, the authors also suggest mitigation measures such as:

(a) carrying out awareness raising campaigns emphasizing the idea of “Leave No Trace” and promoting this concept to locals, tourists and other beach users;
(b) increasing specific clean-up activities, especially in summer during the high touristic season;
(c) intensifying direct intervention by the means of patrols and signs;

(d) securing legislative actions which prohibit litter dumping in rivers, as the Ishmi is significantly polluted by Tirana County;
(e) securing legislative actions for bans of certain items as foreseen also under the EU Single-Use Plastics Directive that includes bans on single-use plastic cutlery, plastic plates, plastic straws, cotton bud sticks made of plastic and plastic balloon sticks, along with oxodegradable plastics, food containers and expanded polystyrene cups;
(f) promoting wider awareness among the youth and students on the consequences of the presence of marine litter in the oceans [11].

Walther et al. provide a thorough overview of plastic pollution in China, Japan, South Korea and Taiwan in East Asia [12]. Although plastic pollution is a common problem and plastic waste ends up in the East China Sea and Yellow Sea, the countries react differently from an economic and political point of view. The authors state that research, interregional cooperation and ENGOs have to be intensified and hope that this chapter could "inspire a more concerted effort" [12] of policies and management solutions by the different governments.

The case study by Tanchuling and Osorio [13] about microplastics in Metro Manila rivers shows that most plastics present in the rivers derive from fragmentation of larger particles (secondary microplastics) which mostly originate from leakages of solid waste from landfills into the environment. In order to prevent plastic pollution, the authors suggest a better implementation of The Ecological Solid Waste Management Act RA9003, especially by helping local governments technically and logistically, and capacity-building coupled with good governance. The Manila Bay Coordinating Office (MBCO) was formed in order to rehabilitate Manila Bay and monitor pollution sources. Moreover, informal settlements close to the rivers where no collection of solid waste exit are planned to be relocated. However, a higher collection and recycling rate still needs to be achieved.

Lima et al. [14] present the situation in Brazilian freshwater and estuarine systems. The results clearly reveal a knowledge gap about composition and distribution of plastics in freshwater systems. Although several studies have been published about estuarine systems with data about the current situation (occurrence, size, number of plastic particles), transport processes, pathways and environmental factors were not studied in detail. Moreover, information is missing about the source-to-sink relationship. The authors suggest to use this key approach of source to sea in order to better understand the plastic pollution along the Brazilian coasts.

The research on beaches in the Baltic Sea shows the necessity of a detailed monitoring on beaches [15]. Although monitoring activities have been conducted since several years all around the world, there are still many areas underrepresented and not studied in detail. Ershova et al. [15] used monitoring methods by OSPAR, NOAA and the IOW beach litter method and combined them as the characteristics of beaches are not always the same and different parts of the beaches are investigated. Moreover, the new generated information will be integrated in a database so that this information is also available for a larger public. Furthermore, recommendations will be made for the national program of marine litter monitoring for the coasts of the

South-East Baltic Sea. The results will also be used on an international level as they will be harmonized with the international monitoring programs in the Baltic region.

3 Discussion

The 15 chapters in this book volume “Plastics in the Aquatic Environment – Part I: Current Status and Challenges” have raised a wide range of important questions and underlined some essential aspects of plastic pollution research. Despite the fact that studies on plastics have been ongoing for quite some time, there still remain many research gaps and open research questions. Some of these are methodological gaps, which reflect the need for harmonization and standardization of analytical methods, protocols and quality standards. For many reasons, it is not possible to use a single method, thus it is recommended to apply a combination of analytical approaches. Another open research question is the necessity to conduct research using realistic concentrations of microplastics and carry out long-term experiments which would provide a better overview of the effects of microplastics.

Development of bioplastics is thought to be very promising. However, still, advanced knowledge is needed to allow for a better understanding of the interaction between environmental conditions of a medium, material characteristics, microbiology and degradation mechanisms and kinetics. A related research niche here is to look into waste management of biodegradable plastics and the period of decomposition in natural environments. Waste management in general still requires a lot of attention and improvement for many regions, because the quality of solid waste management and the wastewater treatment largely impacts plastic pollution in the environment.

More research is also needed to understand the potential impacts of additives and contaminants in microplastics. Moreover, ecotoxicological studies need to be intensified, including a very important aspect of the risks of the presence of microplastics in drinking water. Identification of sources of pollution and establishment of the source-to-sink relationship are essential in order to develop efficient management measures.

The presented chapters have shown that besides research projects in each country, it is also crucial to establish cross-border cooperation for tackling plastic pollution. As this problem does not have borders, and the level of plastic pollution in one country may affect the water quality and plastic contamination in a water body in another country, it is of paramount importance to join forces and help each other where and when needed. Such cooperation should also include knowledge exchange and capacity building.

Most probably, as science advances, we will face new research questions and puzzles and there will be a need for more advanced research. Hopefully, with the development of new technologies and materials, scientists will be able to answer those questions and provide well-supported recommendations for decision- and policymakers. We are fully aware that the aspects of environmental science presented in this book volume are only a tiny part of the myriad of questions that the environmental science is confronted with dealing with plastic pollution. It would have been an impossible task to gather all of them in one book. At the same time, our aim was to highlight some interesting developments and show potentials and achievements, as well as limitations and constraints of the current microplastic analysis, waste management, bioplastics research, capacities of new models and approaches and promising niches for further investigation. We hope that this book volume will be useful for both scientists and policymakers and that the chapters with case studies will provide valuable information and inspiration for other regions. We are positive that this book volume together with its second part, "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution", has greatly assisted in accumulation and distribution of knowledge and expertise on plastic pollution and we would like to wholeheartedly thank all the authors for their contributions, time and commitment.

Acknowledgements Evgeniia Kostianaia was partially supported in the framework of the Russian Science Foundation Project N 21-17-00191 (2021–2023) "Monitoring of water exchange through the Kerch Strait based on state-of-the-art methods of observations and numerical modeling".

References

1. Stock F et al (2021) Pitfalls and limitations in microplastic analyses. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_654
2. Dierkes G, Lauschke T, Földi C (2021) Analytical methods for plastic (microplastic) determination in environmental samples. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2021_744
3. Endres H-J (2021) Biodegradable plastics – end of life scenarios. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2021_745
4. Green DS (2021) Biological and ecological impacts of plastic debris in aquatic ecosystems. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_509
5. Anastasopoulou A, Fortibuoni T (2021) Impact of plastic pollution on marine life in the Mediterranean Sea. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2019_421
6. Sapozhnikov P et al (2021) Plastic in the aquatic environment: interactions with microorganisms. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2021_747
7. Zandaryaa S (2021) Freshwater microplastic pollution: the state of knowledge and research. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2021_748
8. Cieplik S (2021) From land to sea – model for the documentation of land-sourced plastic litter. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin

9. Horodytska O, Cabanes A, Fullana A (2021) Plastic waste management: current status and weaknesses. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2019_408
10. Kalčíková G, Žgajnar Gotvajn A (2021) Plastic pollution in Slovenia: from plastic waste management to research on microplastics. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2019_402
11. Kolitari J, Gjyli L (2021) Marine litter assessment on some beaches along the southeastern Adriatic coastline (Albania). In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_627
12. Walther BA et al (2021) Plastic pollution in East Asia: macroplastics and microplastics in the aquatic environment and mitigation efforts by various actors. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_508
13. Tanchuling MAN, Osorio ED (2021) The microplastics in metro Manila Rivers: characteristics, sources, and abatement. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_659
14. Lima ARA et al (2021) Plastic contamination in Brazilian freshwater and coastal environments: a Source-To-Sea transboundary approach. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2020_514
15. Ershova AA et al (2021) Marine litter in the Russian gulf of Finland and south-East Baltic: application of different methods of beach sand sampling. In: Stock F et al (eds) Plastics in the aquatic environment – part I: current status and challenges. Springer, Berlin. https://doi.org/10.1007/698_2021_746